Theoretical Prediction of an Observed Solar g-Mode

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Since the beginnings of nuclear weapons research at Los Alamos National Laboratory, there has been an interest in the conditions in stars with similar high temperatures, densities, and pressures. This interest has grown to full-time efforts of a few astrophysicists to become part of worldwide research on stellar astrophysics. This report covers very recent results for the pulsational stability of the sun that have been obtained to interpret just-published [1], line-of-sight radial velocity data of the solar surface. Periods of solar pulsations from these Lagrange point satellite observations indicate global oscillation modes. Here we discuss a single mode that seems to be confirmed as being pulsationally unstable. Our result showing that only a very few of all possible long-period modes should be pulsationally unstable has just been published in a recent *Astrophysical Journal Letters* paper.

For most of 30 years, periods of the observed shorter global oscillation periods have been known to ever-increasing accuracy, and their theoretical prediction at Los Alamos and elsewhere reveals accurate details of the outer solar layers [2, 3]. The new, finally reliable, longer periods of about 1 hour, are for pulsation modes with large amplitudes only very near to the solar center. These extremely difficult to observe modes (called nonradial g-modes) are of great interest, because matching the mode periods reveals information about the solar center temperature and density where solar neutrinos originate. Further, the observed splitting of these mode periods reveals the central rotation velocity. These conditions are found to smoothly match those found from the shorter periods (called nonradial p-modes).

The figure shows the radial and horizontal motion amplitudes (eigenvectors), plus the period weight for the detected $\ell = 2$, g_3 mode. Note the determination of the period, its weight, depends almost entirely on conditions deeper than about 0.2 of the solar radius (near where the gravity acceleration peaks), but not at the very center.

Also shown are the deep radiative damping (dips at shells 415, 500, and 650), the radiation luminosity blocking [4], and hydrogen opacity effect driving of this eigensolution. Damping is due almost entirely to radial motions at these low spherical harmonic ℓ values. Transverse motions are found to be very small in our linear nonradial nonadiabatic calculations. One can see that where the radiation fraction goes to zero at the convection zone bottom, the driving also goes to zero. The near-surface hydrogen ionization driving actually occurs inside the convection zone upper boundary with some radiation still available for opacity blocking to occur anyway.

Across the top of Fig. 1 is a band of data showing the coordinates for the mass depth, the fractional radii, the temperature in units of millions of kelvin, and the helium mass fraction composition Y for various Lagrange shells.

[1] S. Turck-Chieze, et al., "Looking for Gravity-Mode Multiplets with the GOLF Experiment aboard SOHO," *Ap. J. L.* **604**, 1 (March 2004), p. 455.
[2] J.A. Guzik and F.J. Swenson, *Ap. J.* **491**, 967 (1997).
[3] C. Neuforge-Verheecke et al., *Ap. J.* **550**, 493 (2001)
[4] A.N. Cox, *Solar Physics* **128**, 123 (1990).

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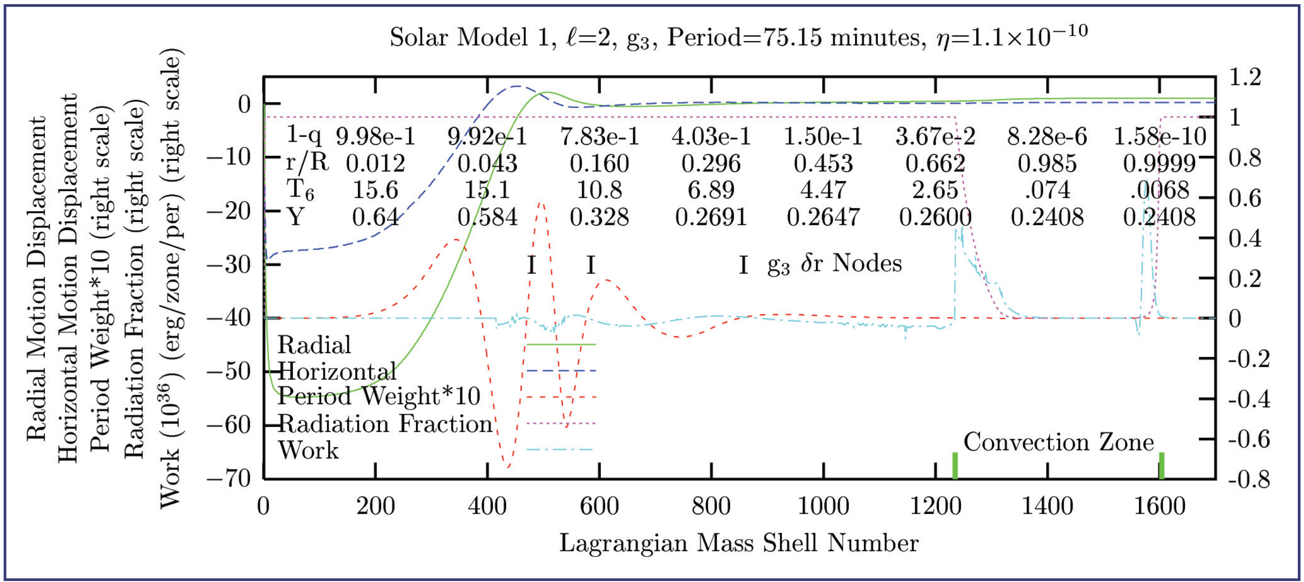

Figure 1—
The radial and horizontal displacement eigenvectors, normalized to the standard δr/r = 1 at the 1700 mass shells model surface, are plotted versus the zone number with the solar model center at the left and the surface at the right. The work done at each linear pulsation cycle is also plotted, showing pulsation driving at the bottom of the convection zone and at the convection zone surface by hydrogen κ effect. The fraction of the solar luminosity due to radiation inside and outside the convection zone is also indicated.